Build a crystal filter to solve VHF interference

When adjacent-channel signals as close as 15kHz to the desired frequency interfere with reception, a crystal filter may offer the best solution to combine low insertion loss with high attenuation.

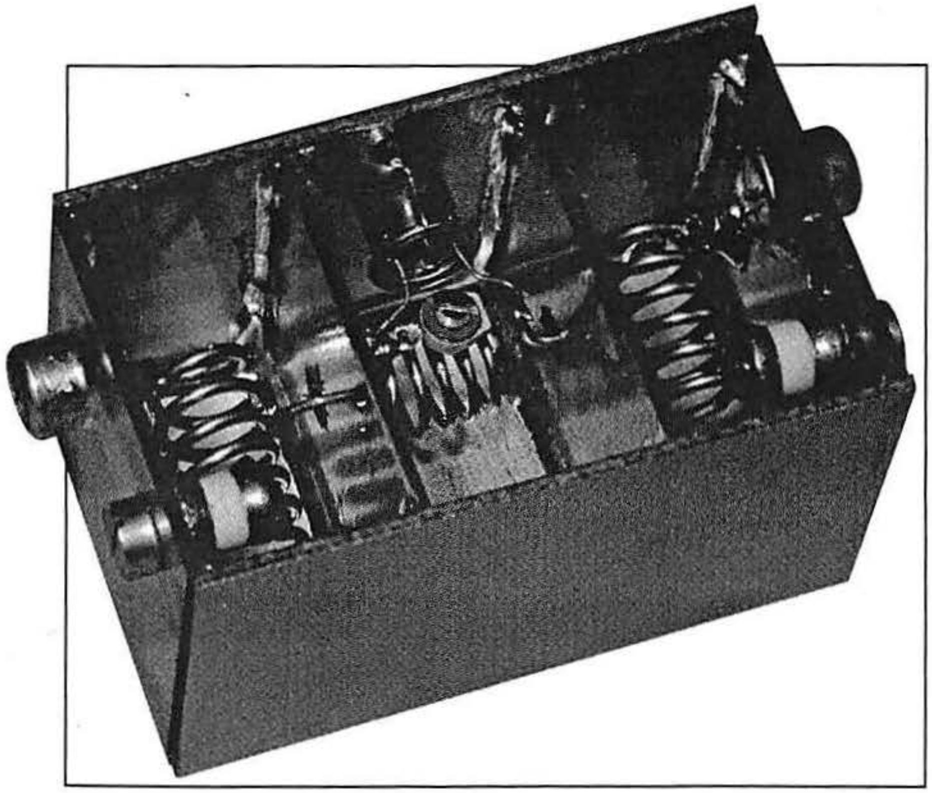
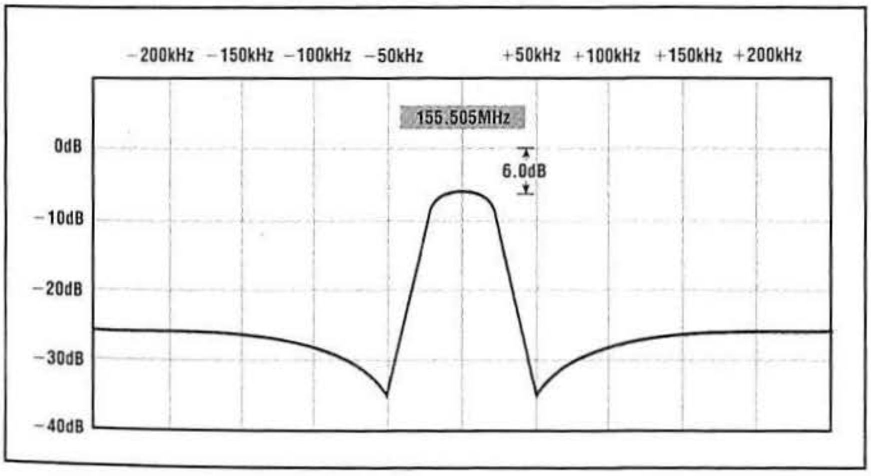


Photo 1. The single-filter, high-pass and low-pass filter of Figure 2 on page 56.



By Patrick E. Buller

One of the best solutions for adjacent-channel VHF highband interference is a crystal filter.

But where do you find one? There are very few crystal filter vendors listed in catalogs and product directories.

A homemade crystal filter can reduce by 25dB a VHF highband only 15kHz from the desired signal with only 1.0dB of insertion loss.

With more and more VHF stations appearing as if from nowhere, adjacent-channel interference has become a problem with no ready or reasonable solution. Large (10-inch) cavities configured as notch filters are inefficient for resolving interference caused by signals less than 100kHz from the desired channel frequency. A device with much higher "Q" is necessary for spacings closer than 100kHz.

High 'Q' solution

Crystals, with "Q" values higher than 70K, are the solution. A crystal filter can be configured either as a high-pass or low-pass notch filter with low insertion loss and, with a second crystal, as a symmetrical band-pass filter.

For many years, Motorola has offered

Figure 1. The Motorola model TLD6340A crystal selectivity curve with an 18.0kHz passband, 6.0dB insertion loss and 40dB maximum attenuation at a spacing of about 120kHz from the center frequency. Attenuation specifications are 13dB, adjacent channel, and 20dB minimum for alternate channels and greater.

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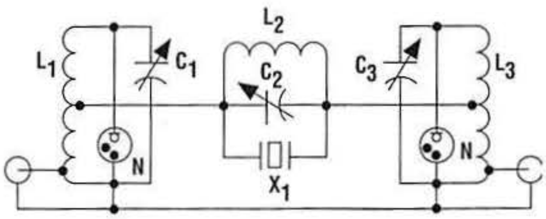
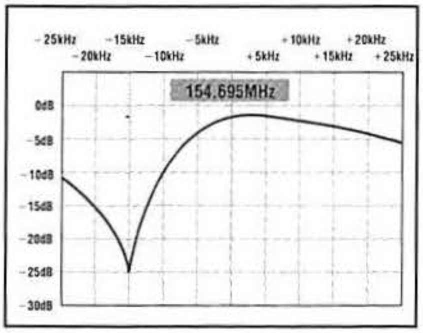


Figure 2A. This schematic diagram represents the best single-crystal, high-pass and low-pass filter based on the Washington State Patrol filter experiments. It uses an AT cut, 5th overtone crystal on 150MHz–160MHz frequencies.

SINGLE-CRYSTAL HIGH-PASS/LOW-PASS NOTCH FILTER

L_1, L_3	7 turns No. 16 AWG, 5/16" I.D., spaced 7/8", tapped at ¾ turn input
	Output tapped at 3½ turns from cold end for crystal
L_2	6 turns No. 18 AWG, 5/16" I.D., spaced 5/16"
C_1, C_3	10pF variable capacitor, Voltronics AP10SD
C_2	8pF ceramic trim capacitor
N	NE-2 neon bulb



'Figure 2B. The response curve of the filter adjusted for high-pass applications.

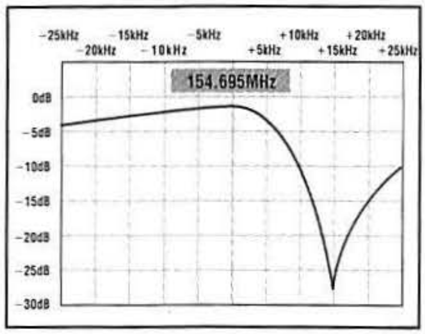
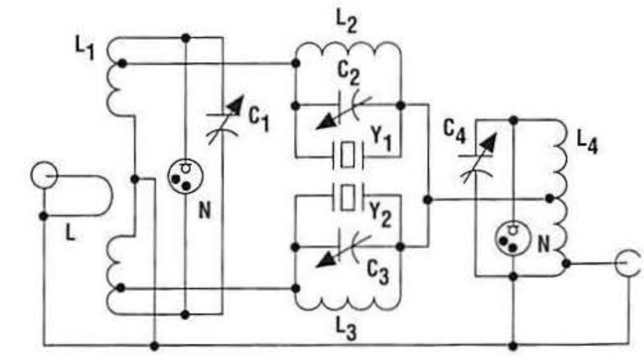


Figure 2C. The response curve of the filter adjusted for low-pass applications.

VHF crystal filters with a passband of 18.0kHz, 6.0dB of insertion loss and 40dB maximum attenuation at a spacing of about 120kHz from the center frequency. Attenuation specifications are 13dB, adjacent channel, and 20dB minimum for alternate channels and greater. Figure 1 on page 54 gives the 1972 specifications.

Crystals in the Motorola device can operate directly across a parallel-tuned circuit; nevertheless, attenuation is about 10dB. This filter has little value as protection from today's adjacent channel interference.



½-LATTICE NOTCH FILTER (NOTCH IS ON CRYSTAL FREQUENCY)

L_1	8 turns No. 16 AWG, 5/16" I.D., with space for 3/4 turn of No. 18 AWG
L_2, L_3	6 turns No. 18 AWG, 5/16" I.D., spaced 5/8"
L_4	7 turns No. 16 AWG, 5/16" I.D., spaced 7/8"
	Input tapped at 3/4 turn
	Output tapped at 3 1/2 turns from cold end for crystal
C_1, C_2, C_3	10pF ceramic trimmer capacitor
C_4	10pF variable capacitor, Voltronics AP10SD
N	NE-2 neon bulb

Figure 3A. The schematic diagram represents a half-lattice filter where the notch frequency is that of the two crystals. For greater bandwidth at the notch, one crystal should differ from the other by the required separation, perhaps 5kHz. The distinct advantage of this method is the quantity of notch attenuation obtainable—nearly 65dB with 2.0dB insertion loss, as shown in Figure 3B. Parallel resonant circuits L2 and L3 shift the crystal's resonant properties for the greatest attenuation.

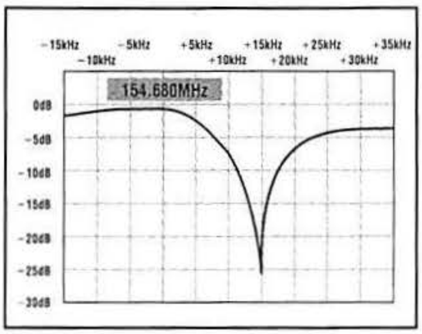


Figure 3B. The response curve adjusted for the high-attenuation, low-pass band-reject mode.

Piezo Crystal, a vendor that was interested in cooperating in the Washington State Patrol filter experiments, can supply AT cut, 5th overtone crystals on 150MHz–160MHz frequencies. Many circuits were tried during the research and development stage that resulted in a more thorough understanding of crystal behavior in this application. The best single-crystal, high-pass and low-pass filter is shown in Photo 1 on page 54 and Figure 2 on page 56. High-pass and low-pass characteristics are shown in Figures 2B and 2C.

Simplified design

The advantage of this design is that the

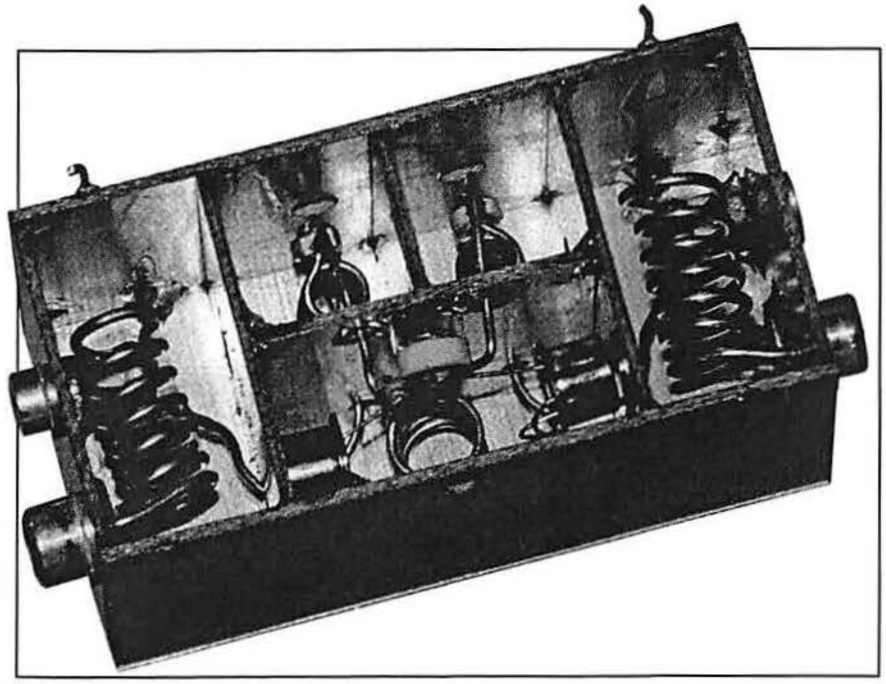


Photo 2. This picture shows the band-pass filter of Figure 4.

crystal determines the pass frequency, and its shunt element determines the notch frequency. This design resembles tunable cavities, used for duplexing and combining where cavity tuning determines the pass frequency, and link tuning sets the reject frequency. This approach to crystal filter tuning simplifies the design. Choose the crystal for your pass channel frequency and tune to the interference.

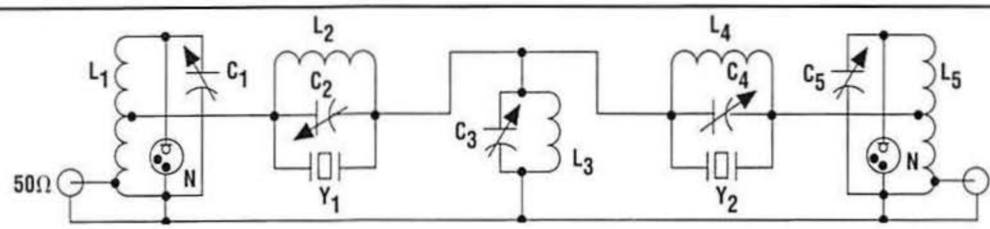
Input and output coils, L1 and L3 in Figure 2, match the 50V input and output line impedance to the Piezo crystal impedance, minimize the insertion loss and provide a small phase shift to compensate for slight crystal differences.

Tuning L2 from high-pass to low-pass, or the reverse, without tuning L1 and L3 does not yield low insertion loss. Changing the "tank Q" to fewer turns and increasing the capacity results in less flexibility in adjusting from high-pass to low-pass applications. All 20 crystals used for research and development matched the same impedance tap on the tuned coils.

Half-lattice filter

Figure 3 on page 58 is the schematic of a half-lattice filter, where the notch frequency is that of the two crystals. For greater bandwidth at the notch, one crystal should differ from the other by the required separation, perhaps 5kHz. The distinct advantage of this method is the quantity of notch attenuation obtainable—nearly 65dB with 2.0dB insertion loss, as shown in Figure 3A. Parallel resonant circuits L2 and L3 shift the crystal's resonant properties

Figure 4A. The schematic diagram of a band-pass crystal filter with two crystals on the same frequency. Each crystal shunt element is tuned to the first adjacent channel above and the first adjacent channel below. The advantage of this circuit is that it can be tuned as a band-pass filter (Figure 4B) or as a band-reject filter (Figure 4C) with higher attenuation than what can be obtained with the single-crystal method.



BAND-PASS FILTER

L_1, L_3, L_5	7 turns No. 16 AWG, 5/16" I.D., spaced 7/8", tapped at ¾-turn input Output tapped at 3½ turns from cold end for crystal	Y_1, Y_2	band pass frequency
		L_2, C_2	tune for notch frequency
L_2, L_4	6 turns No. 18 AWG, 5/16" I.D., spaced 5/8"	L_4, C_4	tune for notch, same frequency as L_2, C_2 for high attentuation, or tune to opposite side of pass frequency for symmetrical response
C_1, C_3, C_5	10pF variable capacitor, Voltronics AP10SD		
C_2, C_4	8pF ceramic trimmer capacitor	N	NE-2 neon bulb

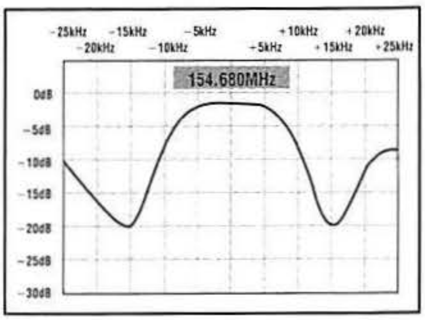


Figure 4B. Response curve of the two-crystal filter adjusted for band-pass applications.

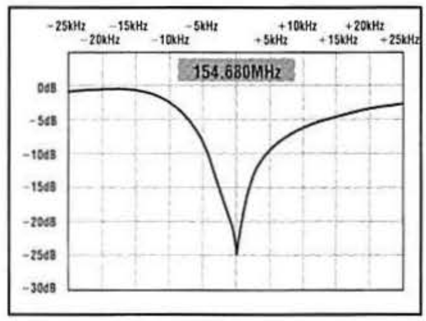


Figure 4C. Response curve of the two-crystal filter adjusted for a single-frequency notch.

Circle (53) on Fast Fact Card

for the greatest attenuation.

Photo 2 on page 60 and Figure 4 on page 62 represent a band-pass crystal filter with two crystals on the same frequency. Each crystal shunt element is tuned to the first adjacent channel above and the first adjacent channel below. The advantage of this circuit is that it can be tuned as a band-pass (Figure 4B) or as a band-reject filter with higher attenuation than the single-crystal method.

Interaction in tuned circuits L2 and L4 prevents uniform attenuation curves in the reject mode. (See Figure 4C.) Its attenuation is better than two filters in series (as shown in Figure 2) by about 0.75dB.

Filter characteristics

With a spectrum analyzer and a tracking generator, it is possible to display the filter's characteristics. Notice in Figure 4A that there are "spurs" (spurious responses) above the crystal frequency at a lower level. These spurs have no effect upon the receiver's "on-frequency" performance.

Field tests with a 25dB notch filter, like the one in Figure 2, reduced a 15kHz adjacent signal from 300mV to 15mV, including the filter's 0.8dB insertion loss. The tests also proved that it interfaced in series with 10-inch cavities without additional loss.

The design of the Figure 2 filter was optimized for close-channel problems, although it can be tuned from the crystal frequency to approximately 100kHz on the low-frequency side and nearly 65kHz on the high-frequency side. For interference control at frequencies beyond 150kHz from the center frequency, there are other, more efficient, circuit arrangements.

Making adjustments

A spectrum analyzer with a tracking generator (or with signal generator and a tracking source) makes adjustments simple. If you are without these instruments, try this approach: Align input and output coils L1 and L2 of the filter, as in Figure 2, for maximum output signal at the received (crystal) frequency. Apply a signal at the desired notch frequency, and tune L3 for maximum attenuation at the output. Always have a valid 50V resistive load on each side of the filter for optimum performance.

Manufacturing 5th overtone crystals at this frequency is rather difficult. The first devices that were tried had little attenuation. At Piezo Crystal, it was theorized that the leads attached directly to the crystal element were too large, restricting performance.

The second-generation devices proved the theory. The 7th overtone has less notch attenuation than the 5th and 3rd overtones.

The enclosure for the crystal filters is made from double-sided printed circuit board stock soldered within each compartment. RCA phono jacks are used for in/out connections. Coils for the single-crystal filter shown in Figure 2 were wound on a common round pencil with a $^{5}/_{16}$-inch diameter.

These filter ideas can be further developed to suit other needs. Someone probably will substitute toroids for the inductors, or perhaps slug-tuned coils. Use what you have.